Australian Government

Department of Defence

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Towards an Analytical Framework for Evaluating the Impact of Technology on Future Contexts

Peter J. Dortmans and Neville J. Curtis

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ABSTRACT

This report provides a framework that supports the capture, classification and collation of technological trends and innovations from their earliest appearance right through to their impact on military thought, both directly, through military application, and indirectly, through impacts on the future context. The approach is centred on postulated effects-based technology concepts, determined through combinations of enabling technologies and designed against delivering required battlespace effects. Such a framework provides the capacity to identify incremental (evolutionary) trends and some truly revolutionary (disruptive) technologies that have the potential to substantially impact on future warfighting operations. It also discusses the roles of and relationships between the various participants in such a process.

RELEASE LIMITATION

Approved for public release

Published by

DSTO Systems Sciences Laboratory
PO Box 1500
Edinburgh South Australia 5111 Australia

Telephone: (08) 8259 5555
Fax: (08) 8259 6567

AR 013-034

Submitted: June 2002
Published: February 2004

APPROVED FOR PUBLIC RELEASE

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Executive Summary

In order to strategically position the development of its military capability, the Australian Army endeavours to utilise identified future contexts to support their development of warfighting concepts that will shape capability development well into the future. This necessitates an understanding of the means to achieve the desired effects in an environment where changes wrought by scientific and technological innovation are largely uncertain. Between the military planner developing warfighting concepts and the scientist inexorably advancing basic knowledge are the technology middlemen. They transition scientific advances into enabling technologies and integrate sets of these into viable, realisable and useful technological concepts. From these and knowledge of the military requirements and operational context, new military applications can be identified and appropriate battlespace effects invoked.

This report develops and discusses an approach for linking scientific discovery with the development of warfighting concepts, by channelling scientific and technological innovation in a militarily useful direction through the medium of effects-based technological concepts. This approach links together the various elements to provide "roadmaps" that lead to technological concepts. The outcome of such an approach can be used in two ways: if technology is near maturity, we can evaluate the likely benefits, threats and timescales of any innovation. Conversely we can identify those areas that require further work to realise useful outputs. The latter case is particularly apposite where technologies are forecast to fundamentally change the way systems operate. The implications of technological change upon future society cannot be ignored either. Therefore the capacity to postulate future contexts cognisant of technological innovation provides a means for both the development and evaluation of future warfighting concepts produced by military planners. These then inform the development of future warfighting concepts within appropriate future combat paradigms.

An important facet identified in this paper is the distinction between evolutionary ("incremental") and revolutionary ("disruptive") technology innovation. This disruptive aspect of technological advancement contrasts sharply with incremental improvement where innovations and their subsequent effects evolve in a relatively smooth, continuous manner. While incremental technological change is the norm, disruptive technologies offer great opportunities that can significantly alter the future operating environment and the ways for performing military tasks. As such, cognisance of the impact of postulated disruptive technologies is essential when undertaking medium and long term strategic planning, such as within the development of future warfighting concepts. As such, balancing effort between high-risk disruptive technologies that have the potential to deliver such profound effects, and those that provide incremental advances in capability, but with significantly less risk, has implications for how scientific and technological innovation impacts upon future Land Force activities.

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Peter Dortmans obtained a PhD in Theoretical Physics at the University of Melbourne in 1992 and undertook post-doctoral research at the University of Melbourne and the Instituto Nazionale di Fisica Nucleare in Padova (Italy). He joined DSTO in 1999 and was subsequently posted to the Australian Army's Combined Arms Training and Development Centre in Puckapunyal to provide support to their capability development activities. Upon his return to DSTO Edinburgh in 2002, his work focus shifted to supporting future concept development.

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Neville Curtis obtained his PhD in Chemistry at the University of Alberta in 1981 and undertook post-doctoral reeasrch at the Australian National University. He joined DSTO (Propulsion Division) in 1984 and researched new methods of gun propellant stability management until transferring to Operations Research studies of weapons systems. He spent 15 months in DSTO Central Office in support of the Program Improvement during 1992-3. He returned to Edinburgh in 1994 to work on Operations Research of Land Force activities, particularly those related to dismounted combatants. He is currently Mission Head for Land Future Studies with a focus on the contextual and conceptual aspects of Land Force Operations.

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The future belongs to science,
And those who make friends with science
Nehru

1. Introduction

One of the greatest challenges to any organisation that wishes to integrate long-term planning within its development cycle is to be able to provide an effective and efficient structure for the postulation of future contexts, perform formal analyses to assess the impact of these futures upon the organisation, and proactively develop appropriate strategies as new contingencies arise. For Defence, such challenges are exacerbated by the cost of maintaining a capability, the length of time of the procurement cycle and the long lifetime of most equipment purchased. This means that capability procurements are programmed up to ten years in advance, with further planning for a (largely incremental) future force extending out a further ten years. However the expected operational lifetime of these capabilities extends well beyond that and so, if near term decisions on capability development are to be fully informed, an appreciation of the environment (context) and operating schema (concept) 20-30 years hence is essential. Central to this is an understanding of how emerging technology trends will impact upon both the way war is fought and on the environment within which it is fought. This balance between military-technological application (which directly impacts on the military) and socio-technological implication (which indirectly impact upon the military) must be addressed in future technology studies to inform Army's future Land Force warfighting concepts, as it provides the total context (not just physical environment) against which such concepts should be developed.

In considering this, we cannot limit our thinking to performing environmental surveys and/or eliciting expert opinion on how discrete technologies will develop as this provides little more than a shopping list of potential new gadgets. Indeed, as most changes wrought by technology are the result of the incorporation, integration and application of current and emerging scientific and technological development, lists of individual technology improvements are likely at best to capture incremental improvements. Instead, attempts at identifying those technology innovations that have the potential to produce significant (even fundamental) shifts in society and in warfighting should have prime focus.

A study program is being undertaken to support the Directorate of Future Land Warfare in its efforts to develop relevant and robust future warfighting concepts. This includes:

- identifying the technological enablers for such concepts without necessarily identifying a specific future capability;
- developing and adapting the context within which these concepts can be developed and evaluated; and
- deriving the analytical framework to support assessment and refinement of the concepts.

This essay discusses part of that program, focussing on developing an overall framework that supports the development of warfighting concepts by identifying technological innovation, deriving possible effects-based technology constructs (referred to as technological concepts), and ascertaining some of the impacts and effects that application of these can have on the future battlespace. We envisage that this provides a means of appreciating the potential military utility of postulated technology concepts. We note that given the often subjective nature of futures work, the approach taken will be largely qualitative.

This report thus provides an analytical framework that supports the capture, classification and collation of technology trends so as to determine the potential implications of such trends on future military activities. It suggests a construct for linking scientific discovery to military application through the postulation of technology concepts. An overview of technology forecasting and the requirement for a workable 'taxonomy' is provided. The report then discusses how to view such technology innovations both in terms of the direct impact of technology on the battlespace, and the more subtle indirect impact felt through cultural change that, in turn, can change the operating context. Some techniques for capturing technological innovation are discussed. Of course, we recognise that this work is in its earliest stages of development and is subject to further refinement. Finally we note that concurrent with this work, activities are being undertaken on developing a construct for the Army as a system in light of the incorporation of technological change [1], identification and integration of analytical techniques that best support concept analysis [2, 3] and technology trend surveys [4, 5].

2. Technology and warfighting concepts

The identification of current and emerging technology trends and their potential application to Land Force in the Army-after-next (AAN) timeframe assists the development of future warfighting concepts that support long term capability development and the migration from current and projected force structures. This is not a simple process, as Figure 1 indicates. There is the continual interplay between the technological (technology concepts), cultural (changing contexts) and in our particular case military (warfighting concepts) views. Each of these emerges from specific elements (such as scientific discoveries, technological trends, and R&D innovation for technology concepts), and the relationship between each is mediated through the interaction with the other elements (such as technology concepts informing and being informed by warfighting concepts through such mechanisms as battlespace effects, military applications, and future needs). Certainly, balancing the opposing underlying pressures of technology development, 'technology-push' (evolutionary momentum) and 'environmental-pull' (decision-based formulation), is key to balancing the relationships depicted in Figure 1 [6]. That is, not only the technology-push concepts, but also the environmental-pull concepts that respond to institutional and military needs must be considered (e.g. the development

of an AIDS vaccine is largely driven by societal concerns). Obviously such a system must be dynamic (to be able to cope with ever changing technologies, modes of warfare and operational contexts) and able to cope with flows in all directions.

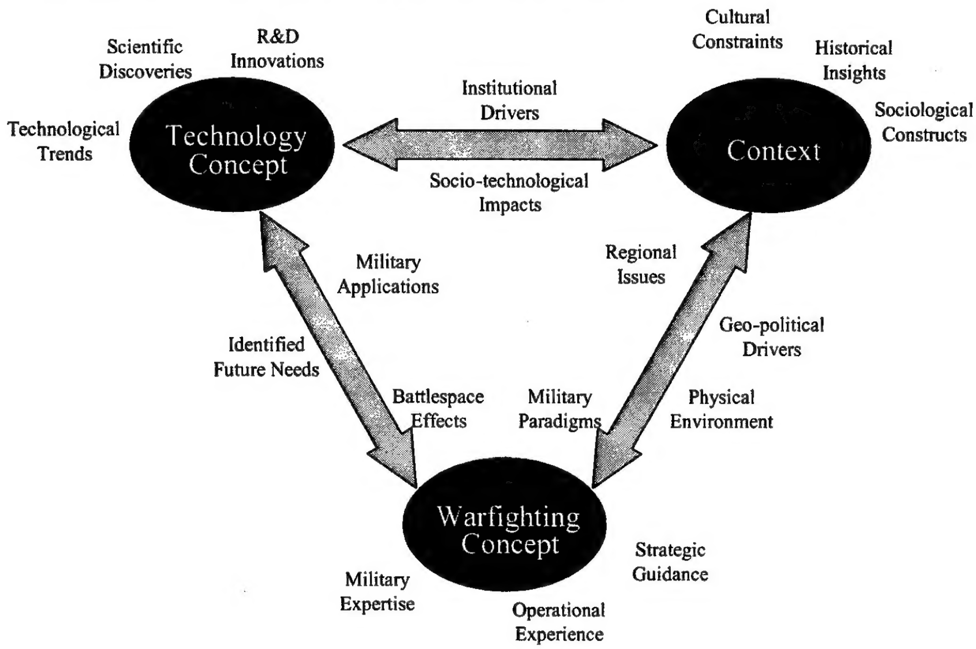

Figure 1: Relationships between technology and warfighting concepts, and operating contexts

When considering technological innovation and the corresponding changes, it has been noted that "a strong phenomena in technological evolution is the notion of technological fusion, where various technologies come together to produce a new technological system far more advanced than any of its predecessors [7]." We agree with this assertion and so, have articulated this through postulate technology concepts — effects-based constructs that represent the possible outputs of aggregating various enabling technologies[1]. This philosophy largely mirrors work being undertaken within the Proteus project [8, 9], an "advanced concepts futures research effort that seeks to pull out innovation drivers and new technology concepts by looking broadly and deeply across plausible alternative futures" [8]. In order to do this, we must first capture and sort technological trends. Identification (and ongoing review) of scientific discoveries and further development sourced through literature searches and scientific experts provides an indication of such trends and, importantly, key indicators that must be met for the realisation of viable application of evolving technologies. We must then determine the interdependence and

[1] We defined enabling technologies to be one of:

- Mature – established areas of knowledge with the element well developed and understood, and/or readily available;
- Emerging – scientific research virtually complete although element is still under development and/or the latter stages of investigation; or
- Speculative – defined as a requirement or suggested as a potential application, with significant R&D still required.

possible innovative applications for aggregated sets of enabling technologies so as to design technology concepts and associated applications. Analysis then allows assessment of the impact, likely high pay off areas, potential vulnerabilities and opportunities created by particular technology concepts.

Context, of course, is the basis upon which we gain an appreciation of the implications of technology and warfighting concepts. Therefore we need to consider the socio-technological impacts of technology on the culture, society and geo-political environments concurrently with the potential military uses of future technology and which is feedback from these. Of course, this requires an appreciation of the potential future context within which both technology and the military will find themselves. Hence historical, sociological and cultural knowledge will inform the development of future contexts against which analysis of military concepts can be made.

3. Overview of previous efforts of technology forecasting

3.1 Formal efforts in technology forecasting

The 'art' (though not necessarily 'science') of predicting technological innovation is very popular. However, on many occasions it is little more than seemingly gratuitous guesses as to the achievements of that predicted by popular science fiction (for example, see Ref. [10]). While such efforts will predict some of the upcoming innovations and associated dates, these are generally self-evident and more a matter of 'market research' in mainstream scientific trends [11]. Science fiction on the other hand is based in lateral thought and provides an alternative source of innovation. However it is of little use if it cannot be linked (even philosophically) with emerging technological trends. Hence the role of technology forecasting is to link novel future concepts with the existing scientific reality. Our aim, then, should be to identify (forecast) and support the translation of scientific innovation into tangible technology constructs.

Some have taken a structured approach to forecasting against a backdrop of its practicality, and with some level of success. For instance, the Japanese National Institute of Science and Technology Policy has undertaken six 'Technology Forecasting Surveys', (e.g. Ref. [12]), aiming to predict innovation out to 30 years (see Ref. [13] for a summary). Using a Delphi approach (described in detail later), a large number of experts was surveyed to capture their predictions on the technology advancement and realisation, along with the timeframe within which they believed this would occur. The results from the survey were collated and analysed to provide some bounds of time of realisation. Analysis of the first survey forecasts [13] indicated the utility of the approach with 28% of predictions being fully realised, and 64% either partially or fully realised.

To make predictions about technology innovation, there is some advantage in amalgamating various techniques. Indeed, the George Washington University (GWU) Forecast [11] employs such an approach to forecast possible timeframes for identified technological innovations, ranging from environmental scanning, trend analysis, Delphi and scenario building. With this they profess to make reasoned predictions out to 30 years[2]. Similarly, an analysis of the impact of integrating bio-, nano- and information technologies (out to 2015) has been made [14]. While this work had a particular focus, this does indicate the utility in extending any analysis of technology change to the development of technological concepts that broadly describe the effect of aggregating and synergising technologies. These technological concepts can then form the basis of analysing the impact of technology and highlighting areas of high value.

There is a hypothesis that suggests that innovation within the military is more rapid during wartime (including the build up) [15] — that is, at a time where potential threats are evolving so as to make current capabilities less effective in their ability to cope with the changing landscape. One might suggest that this represents a broader cultural process where threats to an enterprise's wellbeing (e.g. an organisation [16] or societal entity) correspond with significant scientific and technological innovation (e.g. during the depressions of 1890s and 1930s). By implication, once the threat is removed there is little reason to innovate. For instance, there was significant effort to develop effective treatments for malaria in the 1940s to 1970s in order to remove it as a threat to southern Europe and to protect military personnel in operations in malaria-prone environments such as Vietnam. However, recently there has been little further development in vaccines to treat malaria in recent years even though it is a major cause of preventable premature death in the third world, and increasingly so (up by 25% in the past decade) [17].

From the military viewpoint, one might suggest that much of the recent development of technology for military purposes has derived from the adaptation of private sector applications to military circumstances. If this is the case, the increasingly global nature of science and technology in all sectors (including the military industrial complex) may, in future, create problems when nation states attempt to harness multinational efforts for an circumstance that is purely in the national interest. Certainly, within a truly globalised environment, intellectual property and knowledge, along with skill and manufacturing base, may not be available or even sustainable in the event of competing interests and local policies. Given the potential risk this poses, the capacity to effectively forecast military innovations and set in train the preconditions for their realisation if required is essential for the development of a robust future force.

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[2] They noted that, from their experience, the focus of technology forecasting should be in the realm of 10-30 years as assessments in the less than 10 year timeframe are often overly optimistic while predictions beyond 30 years tend to be pessimistic, in their view.

3.2 Prediction in Military innovation

From the military viewpoint, the impact of emerging technologies has been addressed in various forms and for various reasons. Often this takes the form of incremental advances and their impact on the future battlefield [18-22]. In other cases, the focus is predicting where a potential threat might be heading in technological terms [23] or how that threat might employ commercially available technology [24]. This is valuable and does provide the capacity to determine a migration path towards the incorporation of viable technologies into military systems. It can, however, fail to recognise, until too late, fundamental shifts in capability, limiting the capacity to develop truly innovative ways of operating. Often, the focus is generally on the status quo in terms of military systems and environment. The starting point is to determine how the military currently operates and any known capability gaps, and then consider the technology implications. Therefore it risks missing significant opportunities that such technology might afford, especially if major changes in military structures are realised. So, while keeping in mind the broader impact on force structure, such techniques have their greatest utility in the immediate (near-term) inclusion of recently commercialised technologies.

Of course, what would be better is to identify those technologies that are capable of delivering orders of magnitude enhancement to military capability. Within the business community these have been described as 'disruptive technologies'[3] [16, 25, 26], and defined as technologies that fundamentally change the way a system operates. While they may be difficult to forecast in advance, they are essential if we wish to be at the leading edge of capability. Taking this into account, technology concepts postulated for the AAN timeframe must not only have military application but have far reaching impacts. Hence a more strategic view of technological development must be taken [27, 28] in order to identify and articulate the nature and structure of future operations. We propose to overcome this by employing a backcasting process [29] (where future technology concepts are postulated by a perceived future needs rather than anticipated from current trends). We would then employ a forecasting process to project forward current trends and then identify the potential migration paths that have the potential to support the technology concepts realisation.

3.3 Enabling technology list

While it is important to have a structured approach for capturing technological development, it is essential that these be captured in an effective manner if one wishes to perform any meaningful analysis of these technological trends and the potential synergies that might be realised. Hence, the development of a taxonomy that allows a consistent and meaningful categorisation of science and technological components and concepts is ideal.

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[3] This term has the potential to be misused or misunderstood. We see it as a technology that either presents a completely new way of doing things, e.g. wireless transmissions, or as effecting a change of significant magnitude in a current concept, such as the introduction of the horseless carriage. Some areas are clearly only incremental, such as the replacement of black powder with gunpowder, whilst others such as the tank will be contentious.

However, this is a most difficult activity and has so far eluded those that have attempted to develop a conclusive workable classification of technologies [7]. Certainly there are multiple ways by which technologies might be aggregated and sorted, and many scientific and technology fields are just convenient constructs which hide the fact that there is considerable overlap between various fields of endeavour (e.g. between chemistry, biology and biochemistry). While it is beyond the scope of the current report to develop a workable taxonomy (though a preliminary taxonomy is being developed [30]), it is useful to consider how others have approached the organisation of technological assessments, as many others have attempted to categorise emergent technologies at various levels, and a major outcome of subsequent endeavours in this area is the development of such a taxonomy. We summarise selected examples in Appendix A and report further details in the text below.

STAR21 Technology Forecasting Assessments

STAR21 [27] was a 1993 study that attempted to identify the major technological trends and associated applications of technology for the (U.S.) Army in the 21st Century. In doing so, it described technologies in two ways. Firstly, 11 major trends are identified that broadly have cross-discipline influence (e.g. "Materials design through computational physics and chemistry"). Beyond these, it identifies a number of disciplines (e.g. "Optics, Photonics and Directed Energy") from which discipline-specific trends are identified ("Optical sensor and display technologies"). These are, in turn, usually sub-divided into particular technologies and applications, such as 'laser radar' or 'smart helmets'. While STAR21 does cover the range of technologies and considers their employment, there are some inherent inconsistencies, as the multi-discipline trends do not directly match the discipline specific ones. Indeed, the latter may contribute to the former. Also, technologies and applications are sometimes confused. Be that as it may, the STAR21 report might be utilised to inform the development of technology taxonomy.

RAND Global Technology Revolutions

In 2001 RAND corporation described the potential applications (and necessary synergies) of biotechnology, nanotechnology and advanced materials as applied to Information Technology [14]. While the scope of the work is limited to that particular domain of application, it was suggested that the area chosen had the potential to make significant changes to society. While it provides some insight into how such technologies might be of interest, the structure employed to categorise discrete technologies was somewhat inconsistent, again mixing scientific fields with technological development and application. However the report does provide a mechanism for integrating technologies and determining and assessing their effects.

NATO Land Operations 2020

The Research and Technology Organisation of NATO produced, in 1998, a study focussed on the implications of scientific trends on land operations in the year 2020 [28]. A set of 10 broad technology areas was deemed to be of special importance. These ranged from scientific concepts to emerging technologies and technology concepts, and were mainly focussed on incremental advances to current technologies. The study also identified four

of these as key emerging technology areas and six emerging technology applications (such as 'precision attack'). While there was only a limited effort in identifying technological trends, the report did endeavour to directly link those technologies to a set of six critical Army functional areas. There is potential to leverage from this report the way to link technological concepts to battlespace effects (via military applications).

GWU Forecasting activities

The George Washington University Forecasting activities have been ongoing for some time. In their most recent work [11], they employed the Delphi method to identify emerging technologies, and determine the probability and cost of them being realised (through the collective opinions of experts in the field). The employment of such an approach in our context is likely to be very beneficial as it provides us with the tools for capturing, collating and evaluating technological concepts. In addition, by defining probabilities of realisation (and associated standard deviations), we have the opportunity to employ techniques such as Bayesian Belief Networks [31] and Monte-Carlo simulations to identify the possible array of technologies available at any given time.

UK Ministry of Defence Technology Taxonomy

In 1998, the UK Ministry of Defence developed a technology taxonomy as part of (or to underpin) its technology plan [32]. Their approach was to divide technologies into three streams, "underpinning enabling technologies", "system-related technologies", and "military assessments, equipments and functions". These, in turn were divided into disciplines (e.g. "structural materials and structural effects analysis", "propulsion and power plants", and "platforms" respectively for each of the three streams mentioned above). Each discipline was then disaggregated into particular technologies (82 identified), systems (93 identified), and equipments or functions/tools (43 identified). From the philosophical point of view, such an approach is not unlike what is suggested here. However, the linkage between the various components is unclear in such a list especially when it comes to aggregating discrete elements together. Be that as it may, the particular items within this taxonomy are very likely to provide the basic blocks for any subsequent taxonomy.

DSTO Emerging Technology study

In 1996 DSTO produced a document that looked at the impact of a number of near-term (evolutionary) technologies on the future battlespace [19]. That report provides invaluable information on how technology may impact on how the Australian Defence Force operates, especially within the 5-10 year timeframe. However, it lacks any real attempt to articulate revolutionary emerging technologies and/or technological concepts. In addition, the recent advances made in scientific disciplines and the current crop of emerging technologies mean that there is some need to revisit that report with updated information.

Other taxonomies

A number of other agencies in many countries have endeavoured to develop taxonomies associated with technological development (see Appendix A for some of these lists). They include the US Department of Defence 1989 list of "22 critical technologies" that focussed

largely on optical, photonic, electronic and energy systems, the 1990 U.S. Department of Commerce "12 emerging technologies" (largely scientific and/or technological concepts like 'superconductors' and 'biotechnology'), the 1993 German BMFT "100 critical technologies" (grouped under nine generic headings), and the 1990 Japanese list of "101 new technologies and products". This tends to indicate that, depending upon the particular viewpoint, different classes of taxonomy can be developed.

4. Technology trends and technological changes

4.1 Defining technological and scientific change

In his seminal work "*The Structure of Scientific Revolutions*", Thomas Kuhn [33] identified that scientific discovery is not a smooth, continuous process, and that established 'scientific truisms' are in reality models, "limited representations of reality that crack when strained, producing anomaly and crisis" [34]. In effect such models are designed to provide the best description of our current state of knowledge and hence are under continual challenge as new knowledge emerges. Indeed, historical analysis showed that "New and unsuspected phenomena are repeatedly uncovered by scientific research, and radical new theories have again and again been invented by scientists" [33]. Hence, science by its very nature is revolutionary and has the potential to elicit significant paradigm shifts in the environment within which it exists. This is an important idea. It requires us to consider the impact of technological change in terms of their effects on the environment involved. That is, technological change (amongst other changes) creates the future, which implies that technological forecasting should be considered within a futures space where technology innovations are themselves drivers for change. However, it can become unwieldy to introduce these for every incremental change, and so we divide technological change into those that are evolutionary and those that are revolutionary. As such we employ the concepts of 'incremental' and 'disruptive' change [25] to focus our analysis of technological change.

4.2 Technological change

4.2.1 Incremental

The most common way in which technology develops is through an incremental improvement either to particular aspects of a technology or to the integration of that technology with other technologies in a relatively straightforward manner. In this sense, the change is evolutionary, focussing on making the key drivers of the technology (such as speed, weight, endurance or strength) better. In effect, it is a relatively smooth transition across time that does not significantly change either the operating environment or the method of operation (e.g. continuous improvement in the definition of computer monitors). Commonly, attempts at technological forecasting fall into this category, where

the intent is to map the pathway from the current situation to derived technological concepts and highlight the development that must be met in order to realise the technology. The incremental approach provides the capacity to assess the viability of proposed technological concepts because those that cannot be mapped from now until their realisation would highlight a need for a more focussed analysis. When looking at the short to medium term, this is the most practical way of performing technology planning.

4.2.2 Disruptive

The incremental approach, however, has a fundamental problem. It may miss those technology innovations that "bring not only new opportunities to grasp, but threaten to replace old ones" [7]. Indeed, fundamental changes to the way users employ technology are often realised by new users employing technology in novel ways and in the process creating new functional entities [25]. For example, the transformation from analogue to digital systems, such as replacing vinyl records with compact disks, and replacing diodes in computers with transistors are all examples of technological changes that fundamentally shifted the process for doing things and, in doing so, created new opportunities and previously unrecognised outcomes. With this in mind, Bower and Christensen [25] asked the question why do established companies that "invest aggressively – and successfully – in the technologies necessary to retain their current customers ... fail to make certain other technological investments that customers in the future will demand?". The conclusion was that established companies tended to invest in technologies in order to retain their current customers/market share, which, paradoxically, left them liable to miss future opportunities as new markets emerged.

This led to the introduction of the term 'disruptive technology' [25] to describe those technologies that fundamentally change the way in which businesses operate. Importantly, they pointed out that disruptive technologies did not require the development of radically different technological components (e.g. lasers for logistics and making dumb bombs smart). Rather, novel approaches to integration and employment created new markets that eventually usurped the established one. This is a pertinent point for military planning in a context of evolution (or revolution i.e. revolution in military affairs) from the traditional (2nd wave) warforms defined by mass-production and associated warfighting concepts [35], to the largely digital (3rd wave) ones, which often involve the employment of known technologies in clever ways.

Further research in 'disruptive technologies' [16] focussed on determining why leading industries and businesses seem less able to meet the challenges created by fundamental changes in technology, suggesting that while leading businesses should be in the best position to benefit from the advantages these technologies provide, they did not because they were too close to the 'traditional technologies' and associated processes and practises. These companies were more comfortable with pursuing incremental changes, as this approach had been successful in the past. Therefore organisations without such baggage were likely to be better able to adapt, develop and become significant players [16].

4.3 Forecasting and assessing technological innovations

While it may be a more tractable problem to forecast the direction of incremental technological development and make an assessment of its utilisation, as discussed above, the greatest payoff comes from pre-positioning an institution to meet those challenges that might significantly shift the *modus operandi* — in effect to realise the opportunities that such disruptive technologies might present. Therefore, as Figure 2 indicates, a major aim of technology forecasting is to better understand technological innovation through an appreciation of the emergence and subsequent impact of technologies (both disruptive and incremental). Of course, we can never expect to forecast everything. Rather we identify and capture (some) technology trends, postulate modes of operation and application, and assess their likelihood of realisation and impact, thus providing the opportunity to pre-position ourselves accordingly. Of course, we must be constantly on the lookout for unforeseen emerging technologies to incorporate in any such analysis.

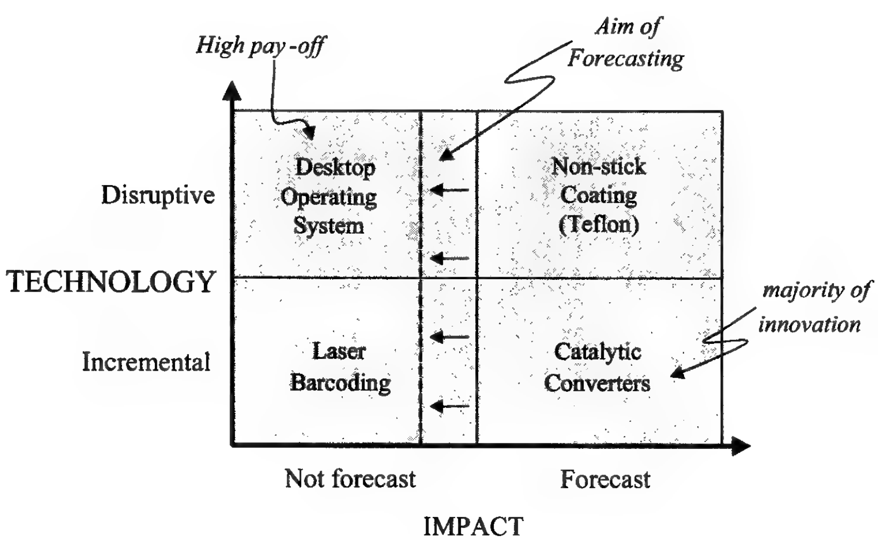

Figure 2: Criteria for understanding technology forecasting

Using the dimensions of impact (forecast or not forecast) and technology change (incremental or disruptive), we can assess, historically, how technology forecasting fared and, so indicate the aim of forecasting (Figure 2). For instance:

- Catalytic converters were an incremental improvement on previous exhaust filtration systems and their subsequent impact was predictable. This is where the majority of innovation occurs.
- Laser barcoding was originally intended to simplify retail sector systems. Its depth of penetration and breadth of application (everything from postal sorting to credit cards to logistics), however, has surprised many and the subsequent impact has been significant in simplifying a number of tasks.

- The Apollo missions necessitated the development of non-stick surface coating materials. Their subsequent application led to systems that were forecast but unachievable until materials such as Teflon were realised and commercially available.
- The almost universal acceptance of Microsoft products as the desktop computer applications is an example of a disruptive technology that is has changed the way we operate. It has significantly reduced the need for typing pools, created a standard of sorts, led to a greater level of utilisation of PC than previously thought possible (at least within the timeframe in which it occurred), and allowed the transmission of documentary knowledge to occur at an unprecedented rate (in combination with other technologies such as the Internet). As with most information technology products, their impact was certainly not forecast.

We believe that the majority of innovation will occur in the incremental/forecast box. It is however, highly likely that the highest pay-off will occur in the box diametrically opposed to this (disruptive/not forecast) though of course identification represents the most difficult challenge. Implicit in this analysis is the notion that one of the roles of the defence scientist is to extend the forecast/not forecast boundary to the left, as shown in Figure 2.

Our aim then, is not to focus solely on forecasting technology, but to gain some understanding of the associated technology development, application and impact. This raises the question of how to establish the link between the scientific bench and the military end-user, and, consequentially, what is the role of the defence scientist and defence (and broader) industry (as will be discussed later).

4.4 Rationale for technology forecasting approach

While many lists have been produced that purport to identify "critical", "emerging" or "key" technologies (e.g. [10, 12, 14, 36]), two issues associated with such lists invite critical review:

- their relationship to a final militarily useful product
- the desire for a consistent taxonomy that supports sorting items at a similar level of abstraction and meaning

With respect to the former (and irrespective of vested interests), it is often difficult to identify how technology advances will be useful. Table 1 gives the notion that a simple concept with a relatively small number of technologies can be readily instantiated with little risk. The driver can come from the perceived need for the gadget, or from incremental progression of current technologies.

Table 1: Thinking forward and backward through technology

	single or small numbers of types technology (*oligo*)	**combined technology (*poly*)**
equipment	readily visualisable – new products as concept or capability technology demonstrators	difficult to visualise except for incremental changes to current systems, likely to involve emergent issues
concept	comparatively simple to invent a new equipment-based concept (e.g. a hovering device that allows sensors to look into windows) and thus direct research into designing the equipment	very difficult to convert a high level concept (such as the "transparent city") into a suite of combined technology products

Far harder, of course, is the treatment of the non-trivial interaction between seemingly disparate technologies, as in the past this has often resulted in novel applications and new paradigms. Therefore it is useful to create an environment which steps outside the current paradigm in order to develop unique and insightful future technological concepts. One approach suggested for incorporating disruptive technologies into military systems is the concept of "kainotypes" [26]. These, in effect, are concept demonstrator devices that can be fielded in real systems. While this might be appropriate for near mature technologies, it may be problematic to incorporate really innovative ideas that fundamentally change how we operate or which make current systems and structures obsolete.

Instead, we suggest an approach of integrating emerging and current technologies into abstract systems and analysing their behaviour through various analytical processes. As such, we have the capacity to postulate a significant number of technological concepts that can then be considered in the light of future warfighting concepts. Therefore, while we may not forecast the effects of all the disruptive technologies that will appear in the next 30 years, those that we do predict will be derived from well considered technologies which have indications of the key indicators to their likely viability, include some form of migration path that indicates how they might be realised, and so provide some level of risk analysis. In addition, taking them into consideration during the development of future warfighting concepts pre-positions Army to incorporate them as they are realised, and thus be true to its "concept-led, capability-based" approach to modernisation. Thus, lateral thinkers, employing brainstorming and other similar techniques, may come up with inventive combinations of new and current technologies and test their viability in synthetic environments (as making such things is likely to be impossible or price prohibitive in the near term). As such, the capacity to relate such concepts meaningfully requires a number of attributes:

- structured information and consensus from subject matter experts that identify a range of potential future technology concepts;
- the postulation of effects-based technology concepts based on the integration of a range of technologies;
- the capture of those scientific and technical advances necessary for the realisation of a particular future technology concept;
- the derivation of a workable, consistent taxonomy to allow a more effective and meaningful storage and management of related data;

- the creation of a migration path from the current technological paradigm to those identified as likely, viable future technology concepts, in order to understand and audit the developments necessary for their realisation;
- the determination of those attributes, consequential effects and broader impacts which those technology concepts have the potential to provide as a basis for focussing the subsequent analytical efforts; and
- finally, the subsequent identification and description of new capabilities that might emerge from such technology concepts.

Of course, identifying disruptive technology concepts is not a simple task, and one cannot even be certain that all disruptive technologies will be recognised. However, their significance and our reaction to them mean that they must be addressed if our analysis is to be meaningful. Therefore we require an approach that can highlight potential technologies in a systematic and structured fashion. Bowen and Christensen [25] suggested this included identifying those technology concepts that are potentially disruptive and, for each one:

1. determining its impact and significance;
2. locating where it might be usefully employed;
3. determining how it might be realised; and
4. redesigning current practices to effectively incorporate it.

The recognition that a disruptive technology is both a threat and an opportunity is important, as it is how these are balanced that will determine, ultimately, the capacity of the military organisation to effectively incorporate such significant changes wrought by disruptive technologies [16].

5. Scientific discovery, military applications and warfighting concepts

5.1 Rationale for linking scientific discovery with military outputs

Technology has been described as the "useful application of science" [36]. Implicit in this definition is the notion that there is a progression from a scientific discovery through intermediate phases to a product. In our case, new warfighting concepts are the ultimate goal and the challenge is to make them viable from a technological viewpoint. We propose the rationale shown in Figure 3 to illustrate the evolution to military applications and, critically, how they might influence future warfighting. In addition, it displays where the relevant stakeholders in the process are situated (which will be discussed in more detail later).

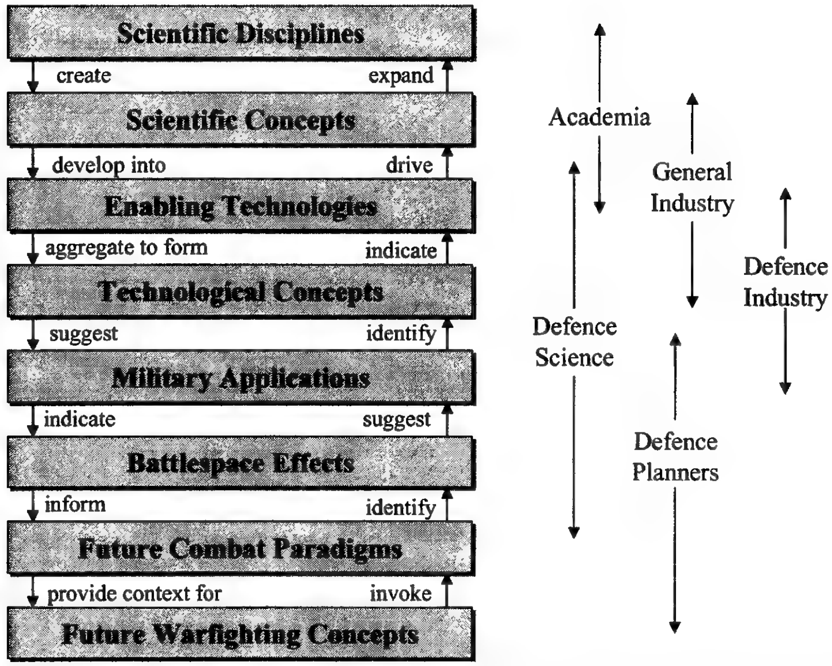

Figure 3: Rationale linking scientific discovery with useable military technology outputs

This approach is based on four related components: "Enabling Technologies", "Technology Concepts", "Military Applications" and "Battlespace Effects". These indicate how we might aggregate discrete technological advances (enabling technologies) into effects-based technology constructs (technology concepts) which can, in turn, be assessed in terms of their military application and so, highlight the battlespace effects that can be impacted. Such a construct allows aggregation of the diverse scientific inputs and relates these to military outputs. It is extended to capture new scientific developments at their inception, link these to enabling technologies, and relate battlespace effects to future combat paradigms, from which future warfighting concepts can be developed.

Figure 3 indicates the relationship between these elements through bi-directional transitions. For instance, scientific concepts develop into enabling technologies from the technological push perspective, whereas enabling technologies can drive the development of novel scientific concepts. It should be noted that Figure 3 does not show the complete picture. The output of scientific concepts from the disciplines will be broadcast in all directions and only some will be directed towards an ultimate usage. Part of the role of the defence scientist is to ensure that identification of these concepts is made and that they are focussed in an appropriate direction. Nor can it be assumed that a predicate cause and effect sequence will be followed; there will not be an automatic progression from the scientific concept to the military end user. Again the defence scientist needs to catalyse the process. In addition, the division of effort between scientists and military planners indicated in Figure 3 becomes a useful construct for understanding each group's role in

the conversion of innovation into warfighting concepts. This formulation divides areas of interest into three:

- consolidation of a list of scientific concepts, enabling technologies and technological concepts (science lead);
- a list of military applications and desired battlespace effects (military-science collaboration); and
- formulation of combat paradigms and warfighting concepts (military lead).

We see the pivotal element of this approach is the capacity to construct effects-based technology concepts, whose purpose is to reconcile the military requirements with scientific discovery. As such, they balance the competing forces of technological push (scientific innovation) and institutional pull (military requirements). As we are constrained by our limited knowledge of such technological systems far into the future, the construct must be conceptual in nature. In addition, it must naturally integrate disparate enabling technology into some meaningful technological end state, where the effects of the construct, not its shape or form, are the basis for development. It must be measurable in terms of its viability, applicability and realisability. Of course, our lack of knowledge of the actual physical end-state means we cannot be prescriptive on how to achieve this.

While important, science is not the only driver for future warfighting concept development. Operational environmental issues, strategic guidance and military experience and expertise all play a significant role. Indeed, the development of future concepts can also feed the identification of technological concepts by suggesting requirements that, if met, would enhance the delivery of a given warfighting concept. Therefore, when considering technological and warfighting concepts together, we are greeted with a dichotomy between performing diagnostics and prognostics. We must both:

- create a concept and identify potential innovations to support it (prognostics); and
- consider a particular innovation and develop concepts that support it (diagnostic).

The effects required can also be driven by the warfighting concepts and thus must be incorporated. This creates an implicit (and sometimes explicit) feedback loop between the technological and warfighting concepts within the defence analysis paradigm. Indeed, as indicated earlier, such feedback can impact on Scientific Concepts.

5.2 Military applications and Battlespace effects

We suggest that the measure of the relevance of any postulated technology concepts should be their potential impact on the environment within which they operate. From the military perspective, that is their effects in the battlespace. There is a strong emphasis on effects here, as both technology concepts and battlespace effects are described in these terms. The role of military application here, then, is to take the potential broader applications of technology concepts and relate them to military requirements through application. Conversely, required battlespace effects may be identified whereby technology effects may be proposed to support the achievement of the battlespace effects.

This effects-based approach is not new. Indeed effect-based planning is being employed increasingly in support of both current operations and future capability development [21, 37-39]. The importance of such effects-based analysis is that the ends required are identified, but not the ways in which to achieve them. Therefore they do not bias any analysis by presupposing or prescribing a solution. In addition, they are by definition generic enough to remain relevant across the temporal dimension covered by the continuous modernisation process (e.g. see Ref. [39] for a suggested list of Land Force battlespace effects). What does change over that time is the expected tolerance levels for those effects (i.e. how quickly or how many casualties etc.). Minimal change to battlespace effects means consistency in analysis and adaptability to new ways of doing business. We suggest here that the core skills[4] approach [1] allows the derivation of a list that is reasonably time independent (though new effects could arise in time) and that can be directly linked to military application of technologies and their subsequent analysis through System Dynamics techniques [40, 41] where the flow and feedback of technologies across the key functional areas can be assessed qualitatively [1, 42]. The drivers here are identified technology-based variables (effectively identified opportunities and/or vulnerabilities) and the associated key technology functions (effectively military-based technological attributes) from which potential (military) solutions can be obtained.

5.3 Deriving warfighting concepts and paradigms from applications of technology

The final steps in the process of translating scientific discovery into military products is the identification of various (generally technology-driven) warfighting paradigms, which, once assessed and determined to be practical, viable and achievable, can be used in combination with battlespace effects to determine the requirements and context for the further development of future warfighting concepts. This is an aggregation of both the military application of technology and the future strategic and physical environments. While the explicit application of emergent technologies to military application can be problematic, a broader analysis of the types of effects they might deliver can support the development of Future combat paradigms[5], such as:

- Niche Wars – small scale, short term conflicts against non-traditional threats with specific objectives and outcomes in mind.
- Space Wars – battle between major powers over control of (in the near future) "circumterrestrial space"[6], with a future eye to hegemony over the Earth-Moon system.
- Robot Wars – autonomous (and/or semi-autonomous) adaptive systems actively engaging within the battlespace in order to prosecute a strategic end.

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[4] The core skills are: engagement; information collection; sustainment; communication; protection; movement; and decision making.

[5] Based on [43] with some aspects updated.

[6] Circumterrestrial space encapsulates Earth to an altitude of approximately 80,000 km. 43, Ibid.

- Nano War – employment of teeming miniaturised systems to operate in a largely independent, undetectable manner.
- Bloodless War – employment of less-than-lethal capabilities to deliver combat outcomes with minimal levels of casualties (even threat), environmental damage and political fallout.
- Bio-technological War – adaptation of bio-technological tools that focuses on attacking/defending the human elements present within and beyond the battlespace.
- Cyber War – attacks on the national and military infrastructure ('own the web').
- Asymmetric Wars – the employment of asymmetric means (e.g. amongst other things the use of nuclear, biological and/or chemical agents and/or terrorist actions) to create significant casualties within and beyond the battlespace in order to create an environment of public fear and uncertainty.

5.4 A worked example – 3-D printers and logistic footprints

Figure 4 is an example of how particular areas of academic research might contribute to the development of scientific concepts and how these evolve into technologies and suggest potential applications. Note that all contributing factors are defined according to their state of development, namely mature, emerging or proposed. We note that these stages of maturity can occur at all levels in the ladder. The particular technology displayed here considers the development of 3D printers [44] in combination with particularly strong material that can be cured by treating fine particles of the compound with a laser. From this, physical gadgets (such as light bulbs) can be built by what is, in effect, a 3D inkjet printer [45]. While the commercial applications are broad, from architecture to art, from the military viewpoint such a tool could be employed to provide in-theatre maintenance. Indeed, there are suggestions that the US Army is looking at this type of approach as a way to allow stranded trucks to make vehicle parts in-situ [44]. For example, the repairs necessary for a broken wheel nut or engine fan could be performed immediately once the component has been created within the onboard laser-driven 3D printer. While the new piece may not have the durability of the original (although we need not assume this), it would mean the system remains operational until a permanent repair is convenient, increasing system availability. In addition, reduced in-theatre recovery, repair and storage requirements would all contribute to a reduction to the logistics footprint. Of course, it is important to distinguish between the enabling technology that might be employed (3D component builder to create and replace broken system components in-theatre) and the means by which such a technology could be countered (increased susceptibility to EW attack), just as it is important to consider the 'anti-concepts' in relation to the pro ones being considered. The other consideration should be how the system as a whole might be impacted (such as a lack of redundancy). By this example, we can see how, through the capture of emerging technologies and even fields of scientific endeavour, and with the assistance of military experts, robust future technological concepts can be identified and assessed as to their likelihood, viability and utility within the military warfighting paradigm.

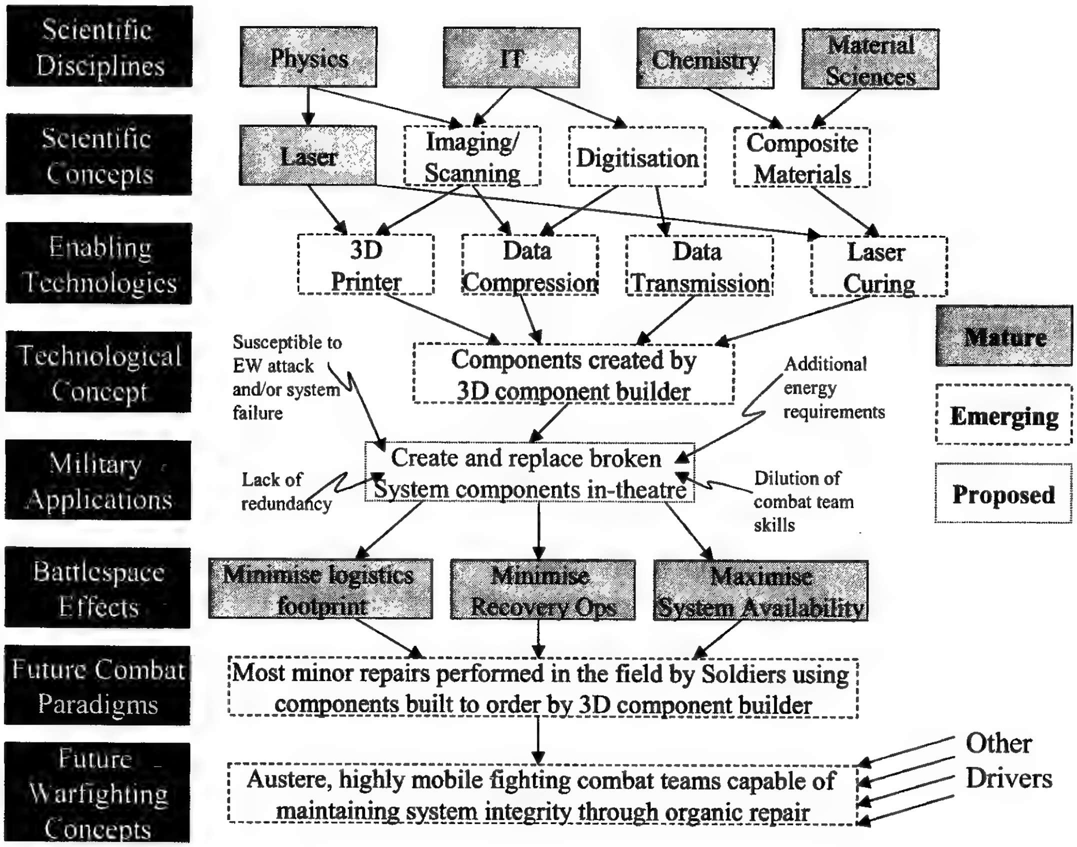

Figure 4: Example of transitioning from scientific idea into concept development

6. Stakeholders in the military R&D process

Of course, it is important to discuss the roles and relationships with industry and academia relative to concept development. Certainly, once technological concepts are identified and evaluated, and the migration paths for their realisation are determined, we are in a position, if we have not already done so, to engage with academia and industry. Using the migration paths as a basis for research requirements, high payoff areas can be highlighted and strategic R&D supported. Figure 3 indicates where each group is most likely (although not necessarily solely) to operate. Note that as we transition from enabling technologies to military applications, we move from those stakeholders focussed on innovation (academia, general industry) to another group focussed on application (defence planners and defence industry). As such, defence science is very active in this transition. The significant overlap of defence scientists and defence capability planners indicates the close relationship that must be maintained between these actors. Defence science, however, remains involved further into the process because of the need to provide analytical support to the development of the concepts. In addition we suggest the defence

science community provides that capacity to link military staff with industry and academia, at least in the early stages of the development of warfighting concepts. As these concepts identify capability requirements, defence industry will, of course, become more involved.

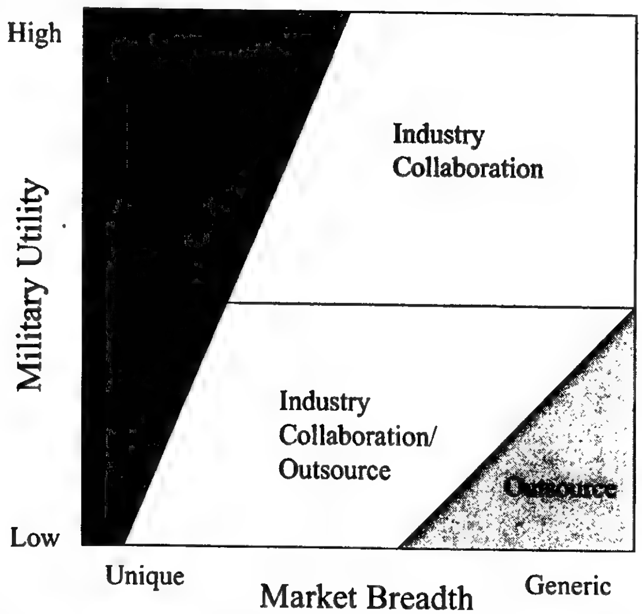

Figure 5: Template for determining the entities best placed to realise military-relevant technologies (adapted from [46])

Having identified where technological and scientific endeavours sit within the research, development and application continuum, we should consider some criteria against militarily useful research. Clearly, no single organisation has sufficient resources to study the full array of potential technologies, even in the applied research component. For Defence, however, sourcing everything externally is not an option either, due to the sensitive nature of much of the work, and limited interest associated with lack of discernable (financial) pay-off. Cost, security issues, embedded knowledge and expertise, and the capacity to readily access components for systems (or systems themselves) when necessary, are but some of the considerations. Hence, it is useful to determine a process for identifying when to outsource and why. Figure 5 (adapted from Ref. [46]) identifies how the Australian defence community might organise its Research & Development efforts in order to balance the issues mentioned above. The drivers are the military utility of the system(s) and its nature (e.g. mortar systems and ECG monitors are unique to particular users while computers and GPS have a broad range of applications). Research areas that have military significance (e.g. armoured systems) might need to be performed in-house. However, as the application broadens to the general community opportunities to work with industry might be considered, although if the system has military significance such work would be undertaken as a close collaboration. As the utility of the application reduces, opportunities for outsourcing might be investigated.

7. Contexts and the socio-technological implications of technology innovation

Technology innovation should not be considered only in terms of its particular area of application (i.e. military). Indeed, as Figure 1 indicated earlier, technology also impacts upon the operational and strategic context. In addition possible future environments which Australia is likely to face within the next 30 year timeframe will impact the development of future warfighting concepts and capabilities by providing both the basis on which such concepts can be developed and a mechanism for evaluating these concepts. While issues such as the geo-political situation, regional stability, and cultural and social perspectives are important in determining future contexts, technology issues such as the uptake and utilisation of technology can play a major role. Technology change can directly impact the individuals and institutions that constitute that environment (e.g. the changing face of large corporations due to developments in information and communication technologies). Therefore it is important to identify the impacts over time of technology innovation and associated socio-technological issues on the strategic environments [42].

However, in order to appreciate the socio-technological implications, it is necessary to identify societal and cultural changes associated with innovations, not just trends. Therefore, having established such trends (technological or otherwise), it is necessary to identify the broad array of possible social norms, as it is these in combination with trends that may develop into emergent practices, as trends provide the broad drivers for change in culture which is achieved through new (or emergent) practices (Figure 6). Having emerged, these practices are given greater impetus by the impact of potential goal-states (issues) that give direction to innovation. Finally, it is the imperatives for change that transform innovation into cultural change which in turn requires social norms to be refined. Therefore our efforts to identify trends and determine their impact on future environments is really an exercise in "looking for emerging *configurations* that reflect a shift in context" [47], as trends facilitate identification of contextual shifts.

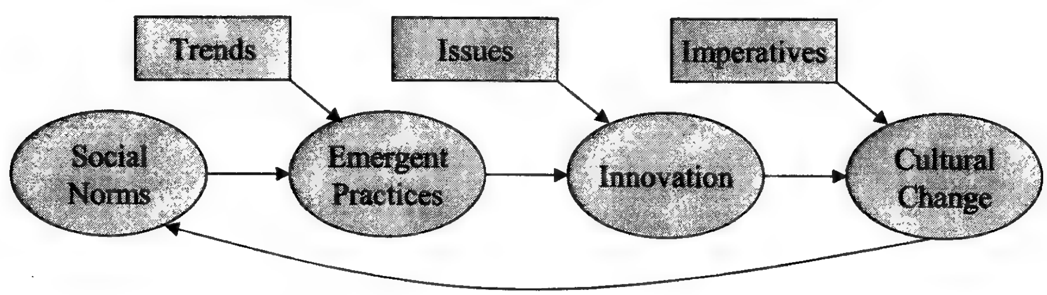

Figure 6: Model for cultural integration of technology

7.1 Embedding Concepts and Contexts into the Continuous Modernisation Process

Identifying and aggregating enabling technologies to produce technological concepts is only one step in the process of incorporating technology in the development of future warfighting concepts. Determination of the viability of such technology concepts is essential if they are to have any utility. Therefore we need to consider:

- the likelihood of the enabling technologies being realised,
- the timeframe within which this should occur, and
- the critical elements on the pathway from our current knowledge to the fielding of a system articulated through the identified concepts.

One approach is to embed this technology migration path within the Army Continuous Modernisation Process, as shown in Figure 7. This allows one to determine the direction of technological change parallel to the development of future warfighting concepts as articulated through the AAN. It also allows the opportunity to identify multiple trajectories for technological change and the associated indicators as time progresses. It also provides an opportunity for the incorporation of vague and/or uncertain concepts (such as Quantum Computing) that are likely to fundamentally change society and the military, but are currently uncertain (both in terms of their realisation and associated timeframe). In such cases the key indicators provide the mechanism for incorporating such technologies into military thinking by identifying the key milestones that must be achieved if these high-risk, high-payoff technologies are to be realised.

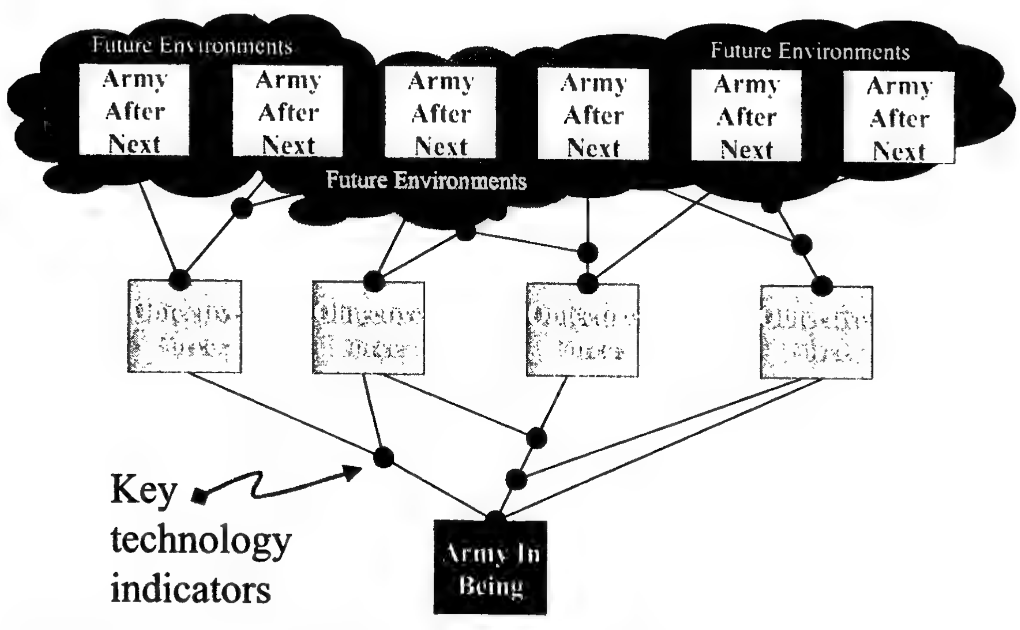

Figure 7: Progression to AAN based on technological development

These are important issues, as it is likely to be extremely expensive, if possible at all, to migrate from an AAN construct developed in light of one projected future environment to another which is significantly different (say the one on the left in Figure 7 to one on the right) if the decisions are made too late in the continuous modernisation process. For example, planning capability development for a conventional land-based threat may create some difficulty if the eventual threat is a small number of highly dispersed and technologically capable military units. Therefore the migration path to any and all futures should be sufficiently developed, providing the key indicators of where trajectories are likely to diverge. As such, this will provide a dynamic and essentially auditable approach to meet the challenges of forecasting in an uncertain environment.

8. Techniques for capturing technological innovation

While future forecasting is not a new art, the development of rigorous approaches to it is. The traditional 'Oracle' approach[7] of indicating one's own view of the future can be useful in identifying particular future trajectories but will always be significantly hampered by one's inherent biases and information limitations. It has been suggested in Ref. [48] that there are four viable (and somewhat rigorous) methods for forecasting future innovation: group consensus (e.g. Delphi); extrapolation of current trends (e.g. environmental scanning and emerging issues analysis); by analogy (e.g. historical analysis); and generation of alternate futures (e.g. FAR). As detailed descriptions and applications of these can be found elsewhere (see Ref. [49] and references contained therein), only a limited description will be given.

8.1 Environmental scanning and emerging issues analysis

The starting point for any analysis of technology trends and futures studies is an environmental scanning exercise. This involves a systematic review of the literature and/or the experts in the field in order to determine the issues and current state of play of a particular field. Using these as a basis, emerging issues analysis then attempts to articulate the future trajectories of these by identifying the pertinent trends. Emerging issues analysis contains three steps [49], issue framing or scoping, issue advancement or exploration, and issue resolution or evaluation. Its strength (and weakness) is that it provides an evolutionary migration path from the current situation out to potential future ones. Therefore we are always in a position to assess the progression along a particular path. However it cannot incorporate revolutionary (disruptive) innovations, as these are not likely to be continuous or incremental.

[7] Oracle - "a person giving wise or authoritative decisions or opinions"

8.2 Delphi-based group consensus

Delphi is a technique in which individual experts are surveyed and their results collated and returned to them (collectively) for further refinement. As such, the consolidated forecasts can capture the range of views on a particular issue from the most optimistic to the most pessimistic. In addition, the interaction between group members in the final stage and/or their responses to other expert opinions provides scope for the development of new ideas as to the potential of the technology under consideration. (See Refs. [11, 49] for a detailed description of the Delphi technique, and Refs. [50, 51] for its application.) Such an approach has been used extensively to capture and collate various expert opinions, most notably the five technology forecasting surveys of the Japanese National Institute of Science and Technology Policy which looked out 25 years (see Ref. [12] for the most recent iteration). In those cases a large number of experts (more than 1000 in all) were surveyed across various fields where technological change can make an impact using a hybrid Delphi technique[8].

The first of these forecasting activities has been assessed [13] and found to be generally quite successful (28% fully realised and 36% partially realised within the timeframe), although in some areas the success rate for the realisation of predictions was considerably lower, such as in "Social Development" (19% realised). This suggests that such a structured attempt to capture is useful, although it does not provide a mechanism to indicate which technologies would be successful. Therefore the capacity to include the key indicators necessary for the realisation of particular technologies needs to be incorporated to allow for some capacity to know whether a particular technological innovation might be realised. In addition, in many areas, the forecasts were based on incremental change only, that is, extrapolation from general trends. Therefore the focus was more on discrete technologies, not on skilful integration of these. Steps must be taken to facilitate the latter.

8.3 Historical analysis

Efforts at predicting military technology applications 20-30 years into the future are sometimes scoffed at as little more than an exercise in scientific 'crystal-ball gazing'. However, taking a historical perspective can provide the basis for noting how technological drivers impact upon military operations and operating environment, whether it be the incorporation of military formations as the Greeks did or the changing utilisation of the infantry to meet the then perceived need [52, 53]. Indeed, the way war is made and the way technology has developed is deeply (at times inextricably) intertwined [15, 35]. For example, the recognition of how digital technology when incorporated with incremental development of such things as long-range missile technology and focussed recruitment and training regimes would lead to a fundamental change in the way war is fought (the so-called "Revolution in Military Affairs") was first recognised only in the early 80s [35] (although there is reference to the ongoing Revolution in Military Affairs ten

[8] Hybrid in the sense that the number of participants was too large to properly perform the group aspects of Delphi.

years prior to this [54]). However, the broader impact of the digital revolution upon society was seen ten to fifteen years before that [55]. So, while drawing an analogy with previous experiences must be performed with some caution, historical analysis of this form can be of significant value [56]. The trick here is to appreciate what may have a significant impact while recognising that we may not know what it is explicitly [57].

8.4 Alternate futures

Development and analysis of future warfighting concepts requires an appreciation of future strategic and operational contexts that might arise. Therefore it is important to create a scenario space that spans the range of activities that might evolve in the future. One of the most powerful ones is to use the field anomaly relaxation (FAR) methods [58-60]. It involves creating scenarios that are cognisant of the possible futures and linking these to current circumstances by way of critical changes to specific environmental axes (such as change in political stability). This provides a basis upon which to assess whether the effects enhanced by technology are relevant, useful and important. In addition, FAR can be usefully employed to facilitate discrepancy analysis where desirable and probable futures are compared (using pairwise comparison of FAR factors) and differences highlighted. This allows an appreciation of what might transform the former (desirable) into the latter (probable), or at least to develop contingency plans to close the gap between them or at least manage the risk associated with less desirable outcomes [54]. Its application to the Australian context [61, 62] has shown the utility of such a technique in planning against a dynamic, evolving and uncertain environment.

8.5 Comparative analysis

When attempting to determine the impact of technology on future social and warfighting environments, it is imperative to determine the significant change drivers associated with transformation from one paradigm to another (or many others); these drivers must be considered in any analysis of future warfighting concepts. Generally, such analyses can be considered to fall into three categories [47]:

- What is *vs* What is – comparison of two current views to determine which is better
- What is *vs* What might be – comparison between current state and a goal state to identify how migration might be achieved
- What might be *vs* What might be – comparison of potential goal states in order to develop long-range plans

As futures work concentrates on identifying and comparing potential future goal states, our focus is generally on the third item of that list and from a technological standpoint. Such comparative analysis may be either qualitative or quantitative in nature, for example using simulations that indicate emergent non-scripted behaviours in conjunction with analysis techniques that facilitate an understanding of the most likely response may be. The latter incorporates subjective expert opinions tools and approaches that look at the implications of actions to systems. Integrating such tools will allow insights between competing concepts to be determined and fed back into concept development.

9. Conclusion

As both a driver and a consequence, technology continues to play a pivotal role in the evolution of military capability. Therefore the capacity to identify those technological concepts that will shape the future environment (both socially and militarily) are essential if Australia is going to be able to pre-position itself to effectively navigate the changing environment within its fiscal limitations. This essay provides a perspective for postulating novel technology concepts to support the development of those future warfighting concepts that will best meet the challenges of our potential future strategic environments. This, in turn, can lead to the identification and delivery of those capabilities necessary to meet our strategic aims. One of the key challenges we face is to anticipate and / or monitor fundamental changes, whether through invention of completely new disruptive technologies or new assemblies of incremental advances in current paradigms. A second challenge is how to leverage off and synergise the efforts of the academic inventors, the defence scientists, those in industry and the end user. Meeting these (and other challenges) will ensure that the Australian Defence Force properly navigates the path between the actual Army-in-being and the conceptual Army-after-next. Having established such a rationale, the test is to employ it effectively in the recognition and elucidation of technological concepts within appropriate military contexts.

10. Acknowledgements

The authors would like to thank Åse Jakobsson for providing information and taxonomy employed by UKMOD, and Joanne Nicholson for her extensive comments.

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Appendix A: Selected technology taxonomy

RAND Global technology revolutions [14]	Bio/nano/materials technology trends to the 2015 timeframe	
Genomics Therapies and Drug development Biomedical Engineering Rapid Prototyping Robotics Nanotubes Quantum Computing	Materials Engineering Smart Materials Energy Systems New Materials Nanomaterials Nanotechnology Self Assembly Bio-Computing	Integrated Microsystems and MEMS Molecular Manufacturing and Nanorobots Biosensors, Nanosensors Bio-Nanotechnology Bioinformatics
NATO LO2020 [28]	Impact technologies for Land Operations in the 2020 timeframe	
Broad technology areas of special importance	***Key emerging technology areas***	***Emerging technology applications***
High power electrical technologies Directed energy weapons Computing technologies Electronic/Information warfare Electronic devices Biotechnology Structural material technologies Human factors and man-machine interface Precision attack technologies Automation and robotics	High power battlefield electrical systems Biotechnology Micro electrical-mechanical systems Novel energetic materials	Precision attack Sensing, information fusion and digitisation Non-lethal weapons and barriers Robotics Simulation and synthetic environments Modular systems
GWU [11]	Emerging technologies from futures experts (Delphi technique)	
ENERGY Alternative (Geothermal Solar/photoelectric) energy sources Organic energy sources Fuel cells Hydrogen energy Fission power Fusion power FARMING & FOOD Genetically engineered food Aquaculture Farm Automation Precision Farming Hydroponic production Artificial foods ENVIRONMENT "Green" manufacturing Waste/pollution reduction TRANSPORT High speed trains Hybrid vehicles Electric/ Fuel cell Cars Hypersonic planes Automated highways	INFOTECH – COMPUTER HARDWARE Parallel Processing PCs incorporating TV, telephone and interactive video Optical computers Data storage Biochips INFOTECH – COMMUNICATIONS Information Superhighway Groupware systems Broadband Networks INFOTECH – INFORMATION SERVICES Entertainment-on-demand Videoconferencing Online Publishing Electronic Banking Telecommuting Distance Learning MEDICINE Holistic Health care Genetically engineered children Gene Therapy	MANUFACTURING & ROBOTICS Computer-integrated manufacturing Mass Customisation Robotics Nanotechnology MATERIALS Ceramic Engines Superconducting Materials Composite Materials Self-assembling materials Intelligent materials SPACE Privatisation of space Manned mission to Mars Permanent Moon base Stellar Exploration Space manufacturing INFOTECH – COMPUTER SOFTWARE Modular software Expert systems Computer sensory recognition Computer translation

Personal rapid transport	Synthetic Body parts Computerised Vision Major Disease Cures	Embedded processors Neural Networks Machine Learning

UKMoD [32]	Military technological drivers	
	Underpinning/ Enabling Technologies	
STRUCTURAL MATERIALS AND STRUCTURAL EFFECTS Metals & Metal Matrix Composite Technology Ceramics, CMC and Glass Technology Polymers & Polymer Matrix Composite Technology Structural Materials Processing Non-Destructive Evaluation & Life Extension of Structural Materials Corrosion and Wear Control Technology Structural Assessments ENERGETIC MATERIALS AND PLASMA TECHNOLOGY Propellants Conventional Fuels and Lubricants Explosives Pyrotechnics Plasma Techniques Explosives Detection Techniques Energetic Materials and Plasma Technology CHEMICAL & BIOLOGICAL MATERIALS Biological/Chemical Agent Defence, Precursors Mid-Spectrum Agent Defence Chemical & Biological Detection Techniques Other non-CBW Chemical Research COMPUTING TECHNOLOGIES Software Engineering Protocol Technology COTS Assessments Architectures High Integrity Computing Secure Computing Techniques	SIGNATURE RELATED MATERIALS & MATERIALS FOR SMART STRUCTURES Acoustic & Vibration Absorbing Materials IR Signature Control Materials Radar Absorbing Materials and Coatings Structural Radar Absorbing materials Smart/Functional Materials for Structural Uses Transparent Materials ELECTRONIC MATERIALS Silicon-based materials III-V Compounds Other Semiconducting Materials Insulators & Dielectrics Carbon-based Materials Superconducting Materials Magnetic Materials PHOTONIC/OPTICAL MATERIALS & DEVICES Optical Fibre Materials/Devices UV/Optical/IR Detector Materials/ Devices Non-Linear Optical Materials and Devices Liquid Crystal Materials Lasers Non-Laser Sources ELECTRONIC & ELECTRICAL DEVICES Device Concepts and Fabrication Device Packaging Device Integration/Reliability Electrical Batteries Electrical Fuel Cells Solar Cells Power Sources Electrical Generators	INFORMATION AND SIGNAL PROCESSING TECHNOLOGY Database Design Digital/Optical Signal Processing Techniques Image/Pattern Processing Techniques Speech Processing Techniques IKBS/AI/Expert Techniques Neural Network Techniques Information and Data Fusion Techniques OA Tools and Techniques Fluid Dynamics Techniques Other Military Specific Algorithms HUMAN SCIENCES Stress - Effects Fatigue - Sustainability of efficiency Human Performance Modelling Decompression Studies Neurophysiology Studies Human Factors Integration Operator Workload Reduction Techniques Performance Enhancing Techniques Training Techniques Task Analysis Modelling Medical Products and Materials Surgical Techniques and Medical Procedures Human Health Physics OPERATING ENVIRONMENTAL TECHNOLOGY Oceanography Terrain/Geographic Information Systems Meteorology Exo-Atmospherics - Space Environment

Military Assessments		
DEFENCE ANALYSIS Policy, Force Development & BOI Studies COEIA System Concept Studies Requirement Definition Studies Scenario Generation Tactical Development & Support to Operations & Training INSTALLATIONS/ FACILITIES Ground Stations Fortification/Defences Battlefield Engineering T&E Facilities	PLATFORMS Surface and Undersea Platforms Fighting Vehicles Logistic Platforms Combat Aircraft Support and Surveillance Aircraft/ Helicopters Unmanned Vehicles Lighter-than-Air Platforms Communications, Surveillance and Navigation Satellites Launchers EQUIPPED MEN Equipped men	WEAPONS Long-range Stand Off Weapons Land Attack Weapon Systems Land Mines Infantry Weapons Anti-Air Guided Weapons Above Water Attack Weapons Gun Systems Small Arms Directed Energy Weapons Non-Lethal Weapons Underwater Weapons Naval Mines
(Military) Systems-related Technologies		
LETHALITY & PLATFORM PROTECTION Warheads Penetrators Platform Protection Measures Battle Damage Tolerance Measures Explosive Ordnance Disposal Mine Detection and Clearance PROPULSION & POWERPLANTS Gas Turbines Reciprocating & Rotary IC Engines Rocket Engines & Ramjets Gun Tube Propulsion - chemical Electric Propulsion - Rotary & Linear Transmissions/Power trains Final Drive Element Ion Thrusters Nuclear Propulsion DESIGN ASPECTS - PLATFORMS & WEAPONS Aerodynamic Designs Hydrodynamic Designs Structural Designs Mechanical Designs Stealth Designs Ballistic Designs GUIDANCE & CONTROL SYSTEMS - WEAPONS & PLATFORMS Navigation Systems Weapon and Platform Guidance and Control Seekers Displays	PERSONNEL PROTECTION MEASURES Physical Protection Systems CB Protection CB Countermeasures SIGNATURE CONTROL & SIGNATURE REDUCTION RF Radar Signatures Micro- & Millimetre Wave Radar Signatures Laser Signatures IR/UV/Visible Signatures Acoustic Signatures Electrical and Electrochemical Signatures Magnetic Signatures SENSOR SYSTEMS RF Sensors/Antennas Micro- & Millimetre Wave Sensors IR Sensors UV/Visible wave Sensors Acoustic/Non-Acoustic Sensors Electrical/Magnetic Sensors CB Sensor Systems Explosive Detection Systems Microsensors for Active Control of Structures MANUFACTURING PROCESSES/DESIGN TOOLS/TECHNIQUES Design for Improved Reliability & Maintainability Design for Improved Affordability Concurrent Engineering and Reduced Design Cycle Advanced Prototyping	ELECTRONIC WARFARE AND DET SYSTEMS DET ECM/EOCM ESM EOPM/EPM COMMUNICATIONS AND CIS RELATED TECHNOLOGIES Communications Technology Encryption Other Communications and CIS Security Techniques Integrated CIS Design Technology CIS Interoperability Standards Non-Co-operative Platform Detection Digitisation of the Battlespace INTEGRATED SYSTEMS TECHNOLOGY Systems Engineering and Integrated Systems Design Interoperability Standards Radiation Hardening Robotics and Automated Systems Reliability and Maintainability of Systems Health Monitoring Systems Safety Systems System Repair Technology SIMULATORS, TRAINERS & SYNTHETIC ENVIRONMENTS Skills Trainer Tactical/Crew Trainer Command & Staff Trainer Synthetic Environments Virtual Reality

Other older lists (from Ref. [36])	Results of 1991 US national critical technologies panel	
<u>MATERIALS</u> Materials synthesis & processing Electronic & Photonic materials Ceramics Composites High-performance metals and alloys <u>ENERGY& ENVIRONMENT</u> Energy technologies Pollution minimisation, remediation and waste management	<u>MANUFACTURING</u> Flexible computer integrated manufacturing Intelligent processing equipment Micro and Nano fabrication Systems management <u>AERONAUTICS & SURFACE TRANSPORT</u> Aeronautics Surface transportation <u>BIOTECHNOLOGY & LIFE SCIENCES</u> Applied molecular biology Medical technology	<u>INFORMATION & COMMUNICATIONS</u> Software Micro/opto- electronics High-performance computing and networking High-definition imaging and displays Sensors and signal processing Data storage and peripherals Computer simulation and modelling

Other older lists (from [36]) (cont)	1990 list of 100+ emerging technologies and products according to Japanese Academic, Government and Industry	
<u>USE OF SPACE</u> No gravity underground experiment system Research base on the moon Linear motor catapult Super tall building Super scale air dome Super tall building demolition technology Underground physical distribution network Underground railway & road facility Underground heat reserve system Artificial island Floating station Marine farm Marine leisure land <u>ENERGY</u> Energy supply technology Fuel cell Solar cell technology Small intrinsic safety light water reactor technology Nuclear fusion reactor High speed breeder reactor Energy Efficiency technology High efficiency heat pump technology Superconducting energy storage <u>ENVIRONMENT</u> Earth warming counter measure CO2 fixation and disposal technology	<u>TRANSPORTATION AND TRAFFIC</u> Superconducting linear motor car Net generation high TC linear motor car HSST linear motor car HTCS (advanced train control system) Bimodal system Next generation automobile Communication satellite for automobile Non gasoline fuel automobile Innovative automobile Techno super liner Surface effect vehicle Intelligent ship Aqua robot Large scale transporting aircraft Ultra high speed transportation Small perpendicular takeoff propeller/jet aircraft <u>LIFE SCIENCE</u> Preventive medicines (Cancer, Viral, Senile) (Self) immunity disease allergy treatment medicines Bone marrow bank Bio energy Biomimetics Artificial organs Artificial oxygen and artificial bio films <u>AUTOMATION</u>	<u>COMMUNICATIONS</u> Satellite/portable communication technology Personal information communication devices VSAT (super small ground station)/satellite data network Imagery communication technology High-definition TV Communication and broadcasting satellite cable TV Multimedia communication technology TV teleconference Broad band ISDN switching system Photo member system Optical LAN <u>NEW MATERIALS</u> Ceramics Superconducting materials Ceramic Gas turbine engine Non-linear optical glass Semiconductors Optical IC Semiconducting super lattice devices Metallic materials Amorphous alloys Hydrogen occlusion alloys Magnetic materials Organic materials Organic non-linear optical electronic devices

Ozone layer destruction counter measure Gas substituting freon-gas Freon recovering processing technology Waste counter measure Natural decomposition plastic Underground waste processing system Underground water processing storage facility	Robotics technology Intelligent Robot Micro machines AI Compound Processing Center Ultra precision machine tools Intelligent CAD/CAM technology CIM/HIM technology Self dispersion control Concurrent engineering	Photochemical hole burning memory Molecular devices Thermoplastic molecular compound materials Composite materials High performance carbon fiber reinforced plastics High performance composite materials
Other older lists (from [36]) (cont)	US Department of Defence 1989 "Critical technologies"	
Microelectronic circuits and their fabrication Preparation of gallium arsenide and other compound semiconductors Software producibility Data fusion Signature control Computational fluid dynamics materials and processing	Parallel computer architectures Machine intelligence Robotics Simulation and modelling Integrated optics Fibre optics Sensitive radars Passive sensors Automatic target recognition Phased arrays	Air breathing propulsion High-power microwaves Pulsed power Hypervelocity projectiles High-temperature, high-strength, lightweight composite materials Superconductivity Biotechnology

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6a. DSTO NUMBER	6b. AR NUMBER	6c. TYPE OF REPORT	7. DOCUMENT DATE
DSTO-TR-1554	AR 013-034	Technical Report	February 2004

8. FILE NUMBER	9. TASK NUMBER	10. TASK SPONSOR	11. NO. OF PAGES	12. NO. OF REFERENCES
E 9505/23/125	ARM 02/066	DGFLW	32	61

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19. ABSTRACT

This report provides a framework that supports the capture, classification and collation of technological trends and innovations from their earliest appearance right through to their impact on military thought, both directly, through military application, and indirectly, through impacts on the future context. The approach is centred on postulated effects-based technology concepts, determined through combinations of enabling technologies and designed against delivering required battlespace effects. Such a framework provides the capacity to identify incremental (evolutionary) trends and some truly revolutionary (disruptive) technologies that have the potential to substantially impact on future warfighting operations. It also discusses the roles of and relationships between the various participants in such a process.